Environmental Test Program for the Mars Exploration Rover Project

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ABSTRACT

On June 10 and July 7, 2003 NASA launched two spacecraft from Cape Canaveral for a 6 months flight to the Red Planet, Mars. The two Mars Exploration Rover spacecraft safely landed on the planet in January 2004.

Prior to the successful launch, both of the spacecraft were involved in a comprehensive test campaign that included development, qualification and protoflight testing. Testing was performed to simulate the environments associated with launch, inter-planetary cruise, landing on the planet and Mars surface operations.

Unique test requirements included operating the spacecraft while the chamber pressure was controlled to simulate the decent to the planet from deep space, high impact landing loads and rover operations on the surface of the planet at 8 Torr and $-130^{\circ}C$.

This paper will present an overview of the test campaign that included vibration, pyro-shock, landing loads, acoustic noise, thermal vacuum and solar simulation testing at the Jet Propulsion Laboratory (JPL) Environmental Test Laboratory facilities in Pasadena, California.

1. INTRODUCTION

NASA's twin robot geologists, the Mars Exploration Rovers, were launched toward Mars in 2003 in search of answers about the history of water on Mars. The first rover, named “Spirit”, landed safely on the surface of Mars on January 3, 2004. The second rover, named “Opportunity”, landed safely on January 24, 2004.

The Mars Exploration Rover mission is part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of the red planet. The program seeks to take advantage of each launch opportunity to go to Mars.

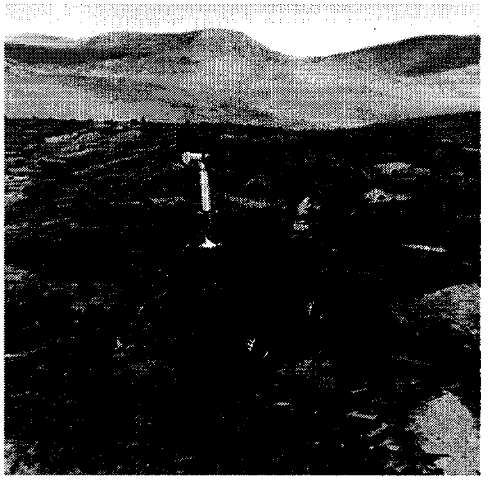

Figure 1. Rover on Martian Surface

Primary among the mission's scientific goals is to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. The spacecraft will be targeted to sites that appear to have been affected by liquid water in the past.

After the airbag protected landing craft settle onto the surface and open, the rovers will roll out to take panoramic images. These will give scientists the information they need to select promising geological targets that will tell part of the story of water in Mars' past. Then, the rovers will drive to those locations to perform on-site scientific investigations over the course of their 90-day mission.

In order to carry out their assigned mission to Mars, the twin spacecraft were subjected to a comprehensive test program at the Jet Propulsion Laboratory. The test program included vibration testing to simulate the launch environment, spin-balance to simulate separation from the launch vehicle, solar-thermal-vacuum testing to simulate the inter-planetary cruise phase of the mission, pressure variation testing to simulate the decent to the Martian atmosphere from deep space, high level shock to simulate the bouncing landing in the air bags, pyro-shock to simulate the deployment of the solar array and mobility components and finally thermal-vacuum testing to simulate the harsh environment of the planet's surface.

2. SPACECRAFT CONFIGURATION

The Mars Exploration Rover (MER) flight system or spacecraft is comprised of the Cruise Stage, the Entry, Descent, and Landing System and the Rover.

The Cruise Stage, which is the configuration for launch and travel between Earth and Mars has a mass in excess 1,060 kilograms (2,300 pounds) and is approximately 2.65 meters (8.7 feet) in diameter and 1.6 meters (5.2 feet) tall.

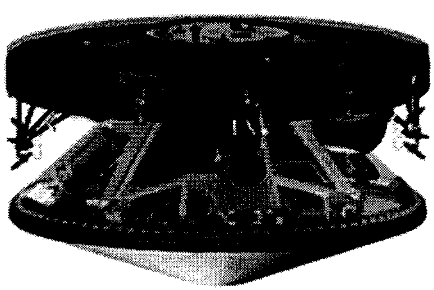

Figure 2. MER Cruise Stage

The Entry, Descent, and Landing System configuration is used for the entry into the Martian Atmosphere and landing on the surface of Mars. The system includes the heatshield and backshell, retro rockets, the parachute, the airbags and lander structure.

The Rover is the heart of the flight system. All navigation, propulsion, mobility, power, and communication are controlled via the electronic systems contained in the Rover. The Rover is a wheeled vehicle that carries the science instruments to different points of interest on the planet. The instruments on the Rover include imagers spectrometers and the Rock Abrasion Tool. The imagers are the Panoramic, Hazard Avoidance and Navigation Cameras and the Microscopic Imager. The spectrometers are the Miniature Thermal Emissions Spectrometer, Mossbauer Spectrometer and Alpha Particle X-Ray Spectrometer. These science and engineering instruments are state-of-the-art tools that will acquire important science information that will help characterize a wide range of rocks and soils that hold clues to past water activity on Mars.

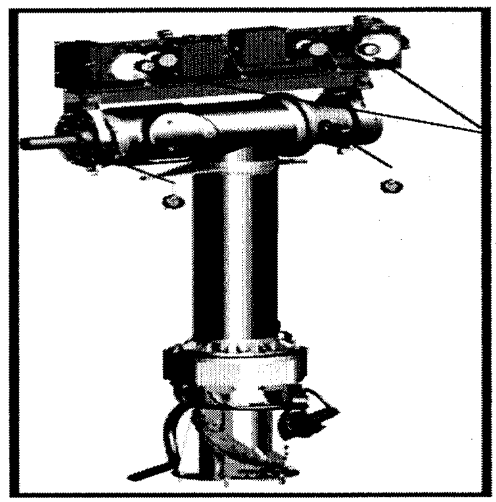

Figure 3. Panoramic Camera Mast

3. OVERVIEW OF THE MER ENVIRONMENTAL TEST PROGRAM

The majority of the environmental testing for the MER project was performed in the JPL Environmental Test Laboratory (ETL) in Pasadena, California. Testing in the ETL included development and flight qualification environmental tests at the component, assembly, sub-system, and system level. Environmental tests included thermal, thermal-vacuum, solar-thermal-vacuum, vibration, shock, landing loads and acoustic noise. The hardware had to be subjected to a test program that would simulate the temperature extremes of the Martian surface and since the MER landler was to be much more massive than the successful Mars Pathfinder Rover which landed on Mars in 1997, a developmental test program was started in the early stages of the MER project to design and qualify components to survive the landing environment on Mars. Numerous vibration, sine-pulse and sine-burst tests very performed on development hardware prior to the fabrication of the flight systems.

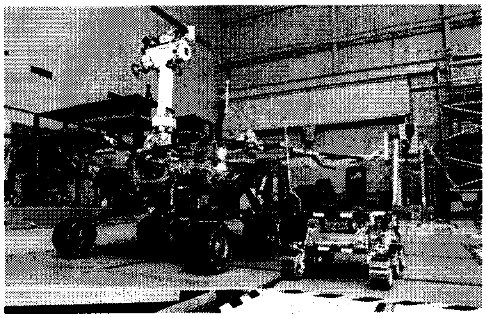

Figure 4. Size comparison of the 1997 and the 2003 Mars Rovers

Other testing included vibration and thermal-vacuum tests of both rovers and flight spacecraft. Additional environmental testing was carried out at other facilities like NASA Glenn Plumbrook Station where the air bags were subjected to drop tests in the very large Space Power Facility vacuum chamber and landing loads testing at National Technical Facilities centrifuge facility in Southern California. Many of the electronic sub-systems such as the UHF radio and the radar altimeter had thermal-vacuum and vibration testing performed at the manufacturer's facilities prior to integration into the flight system at JPL.

Because of the large amount of developmental, qualification and protoflight testing and re-testing required during a very short time frame, the efficient and maximum utilization of test facilities was very important. To help accomplish this very aggressive test program, the ETL maintained close contact with project's management through the use of weekly test scheduling meetings. The use of off-site vibration test facilities at Northrop Grumman Space Systems, and Northrop Grumman Electronic Systems helped relieve the workload on the JPL Environmental Test Lab.

4. JPL ENVIRONMENTAL TEST FACILITIES

The Environmental Test Lab at JPL is comprised of numerous horizontal thermal-vacuum chambers of various sizes ranging from 0.9 meter to 3 meters in diameter by 1.2 meters to 4.5 meters in length. These chambers are capable of high vacuum levels of 3×10^{-6} Torr (4×10^{-6} millibar) with a temperature range of $+125^{\circ}C$ to $-185^{\circ}C$. These chambers were used for component, assembly, and sub-system level thermal vacuum testing of the various MER hardware. The ETL also has two vertical thermal-vacuum chambers. The smaller chamber is referred to as the 10-ft Space Simulator Facility and is 3.0 meters in diameter and 13.7 meters tall. This facility was used extensively for the Martian surface testing of the 2 rovers. This chamber is also capable of high vacuum, but for this test program the majority of the testing was conducted at the Mars surface pressure of approximately 8 Torr (10 millibar).

The largest chamber at JPL is the 25-ft Space Simulator Facility in Building 150. This chamber is 7.6 meters in diameter and 25.7 meters high. In addition to high vacuum and a large temperature range of

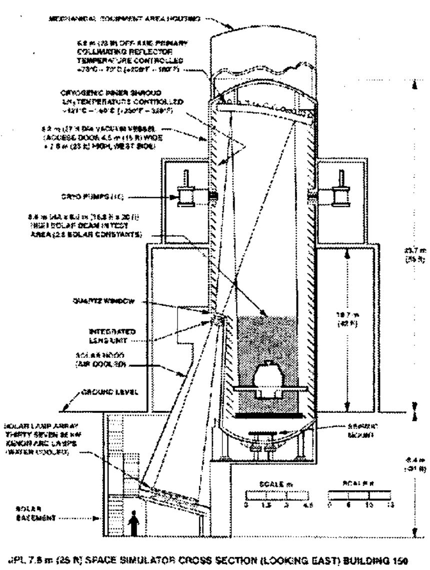

Figure 5. 25-ft Space Simulator

$-185^{\circ}C$ to $+150^{\circ}C$, this chamber has solar simulation capabilities. The simulator can produce a well-collimated 5.8 meter diameter solar beam with intensities of up to 2.3 solar constants and a uniformity of +/- 4%. This chamber was used for MER interplanetary cruise testing.

The dynamics testing area of the ETL is comprised of four electro-dynamic vibration systems of various capabilities and an acoustic noise chamber. The shakers range in size from 20,000 force-pounds (90 kN) to 58,000 force-pounds (265 kN). Redundant digital control systems and 210kW power amplifiers control the shakers. The acoustic noise chamber has a volume of 10,900 cubic-feet (310 cubic-meters) and can obtain sound pressure levels of 155 db.

The ETL has three large class 10,000 (ISO 7) clean rooms that are adjacent to the acoustic chamber and both space simulator facilities.

Data acquisition and recording in the ETL is provided by state-of-the-art digital data systems. In the thermal-vacuum test areas data is collected via a 1000 channel high speed system that records thermocouple output, voltage, current and pressure data from various transducers on the unit under test and from the facility. Dynamic test data of up to 200 channels is recorded and analyzed either by the control system or on various digital recorders.

5. MER DYNAMICS TEST PROGRAM

During the early design stages of the MER test program, numerous tests were performed on engineering models of various structural elements and mobility components of the rover and lander to verify they would survive the landing shock loads associated with the landing on Mars. Testing was performed both on vibration tables and on a large centrifuge.

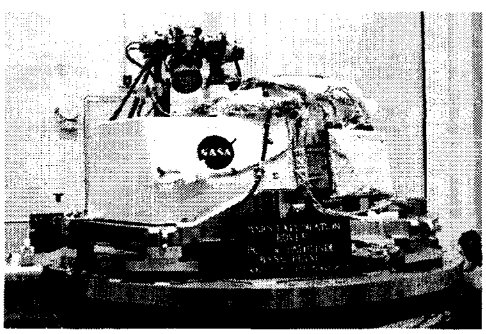

Figure 6. Rover Landing Loads Test

Also during the design phase of the project many vibration and shock tests were performed on the small electric motors, actuators and relays that are used to deploy the many mechanisms on the rover.

During the flight acceptance test phase of the project, numerous assemblies and subsystems were tested in vibration environments. Units such as antennas, mobility components, mechanisms, electronic chassis, cameras, and spectrometers were tested in the ETL and at off-site test facilities. Random vibration testing was performed in all three axis at levels of 5.5 to 8.0 Grms, depending on the requirements of each individual unit under test.

During the assembly, integration and test phase of the project, the flight systems were involved various dynamic protoflight tests. Vibration and acoustic testing was performed in October 2002 and January 2003 on the 2 flight spacecraft with the rover stowed inside the aero shell. In addition the flight rovers were subjected to vibration tests individually. Acoustic testing of the full flight systems were performed at 145 db in the JPL Acoustic Noise test chamber.

Figure 7. MER Flight Spacecraft Acoustic Noise Test

After the completion of vibration and acoustic testing, just prior to system level thermal vacuum testing, the flight spacecraft were mounted on a spin-balance machine to obtain center of gravity and moment of inertia data for the project's structural dynamics engineers.

6. MER THERMAL-VACUUM TEST PROGRAM

During the design phase of the MER project many thermal cycle and thermal vacuum tests were performed on the small electric motors, actuators and relays that are used to deploy the many mechanisms on the rover. Much of this component level testing was performed at the Mars surface pressure of approximately 10 millibar in a nitrogen or occasionally a carbon dioxide (CO_2) environment.

During the flight acceptance test phase of the project, numerous assemblies and subsystems were tested in thermal cycle and thermal vacuum chambers in the ETL. Units such as, mobility components, actuators, mechanisms, electronic packages, cameras and spectrometers under went thermal vacuum and thermal cycle testing. Also, countless thermal vacuum contamination control and planetary protection bake-outs were performed on flight thermal blankets, cable harnesses, mechanical components and electronic assemblies. A typical thermal blanket bake-out was performed at 110°C for 50 hours.

During the assembly and integration phase of the project both spacecraft were tested in a solar-thermal-vacuum environment in the JPL large space simulation chamber.

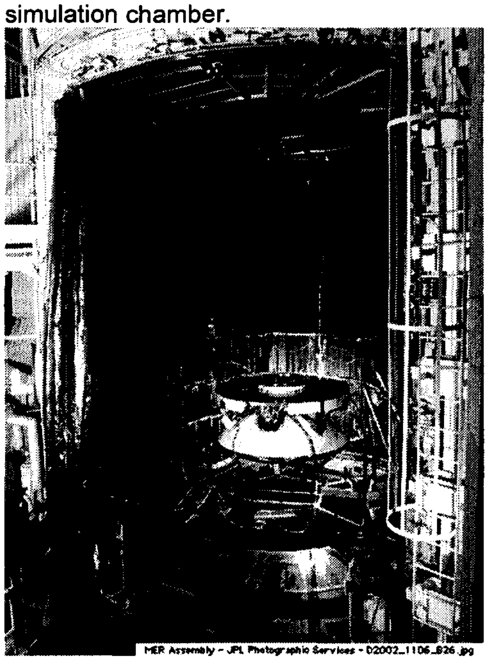

Figure 8. System Level Solar-Thermal-Vacuum Test in the 25-ft Space Simulator Facility

The first spacecraft was tested in November 2002 and the second spacecraft was tested in January 2003. Testing was performed at various temperature and solar levels to simulate the worst-case hot and cold extremes to be encountered during the six (6) months cruise from Earth to Mars. This 10 days of continuous testing was performed at high vacuum levels (10^{-6} Torr range) to simulate the pressure of deep space. There were 3 thruster firing tests during space simulator testing and the chamber pumping system was able to maintain a pressure of less than 3.5×10^{-4} Torr. A special test was performed for the telecommunications system to simulate the decent into the Martian atmosphere. This type of "controlled re-pressurization or backfill" had never been attempted in the JPL large space simulator. To accomplish this, the chamber backfill with nitrogen was halted at 1×10^{-1} Torr and then resumed at an accurately controlled rate to reach 8 Torr in 6 minutes.

Additional system level thermal vacuum testing was performed during December 2002 through April 2003 on the 2 rovers in the JPL 10-ft Space Simulator. This testing consisted of the rovers in the landed configuration in a Mars environment.

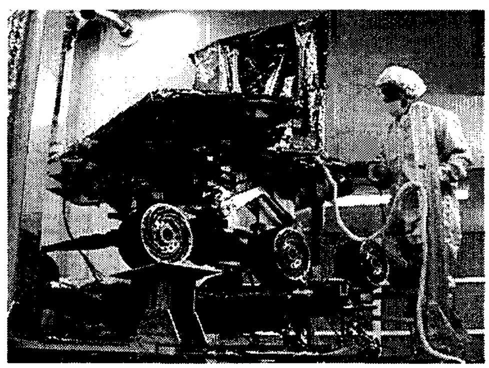

Figure 9. Rover in 10-ft Space Simulator

Chamber pressure was maintained with nitrogen in the 8 to 10 Torr range while the temperature of the shrouds and ground plate were held at various levels between 20°C and –130°C to simulate Martian day and night thermal extremes. During one of these tests various pyrotechnic devices were fired to verify the deployment solar arrays and mobility components.

7. CONCLUSIONS

The Mars Exploration Rover test program was successfully performed in the JPL

Environmental Test Laboratory between early 2001 and spring 2003. Close contact with the project management and the project's engineering staff helped in maintaining a smooth flow of testing through the ETL. At the completion of the environmental test program the 2 flight worthy flight systems were successfully launched in the summer of 2003.

8. ACKNOWLEDGEMENT

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